The 1st East and Southeast Asia Workshop on Inverse Problems and Optimal Control (ESEAW: IPOC)

The goal of this workshop is to bring together leading international experts and junior scientists working in inverse problems, optimal control and related fields. The main focus lies on both theoretical and computational aspects with real-world applications in applied physics, electromagnetics, engineering, geophysics, imaging process, life science, mechanics, medicine, nanotechnologiy, wave phenomena, and many others. At the same time, this workshop will provide an open forum for exchanging knowledge and fostering talents from developing countries in Southeast Asia. The workshop takes place virtually via the Zoom platform between

August 1st - 5th, 2022.

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Speakers:
D. Adytia (School of Computing, Telkom University)
L. Ammann (University Duisburg-Essen)
D.-H. Chen (Central China Normal University)
W. Gong (Chinese Academy of Sciences)
M. Hensel (University Duisburg-Essen)
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Y. Tjandrawidjaja (Technical University of Dortmund)
P. Tong (Nanyang Technological University)
H. Wu (Nanjing University)
W. Zhang (SUSTech)

Timetable

Time (HKT)	Monday, August 1st Chair: **Jun Zou**	Tuesday, August 2nd Chair: **Dinh Nho Hao**	Wednesday, August 3rd Chair: **Sri R. Pudjaprasetya**	Thursday, August 4th Chair: **Li-Lian Wang**	Friday, August 5th Chair: **Irwin Yousept**
14:20 - 14:30	Opening				
14:30 - 15:00	**Hongyu Liu:** Wave patterns inside transparent scatterers and applications	**Mikyoung Lim:** Analytic recovery of a planar conductivity inclusion with a Lipschitz boundary	**Ronald Lui:** A learning framework for mapping problems based on quasiconformal geometry	**Buyang Li:** Convergent finite element methods for the perfect conductivity problem with close-to-touching inclusions	**Wei Gong:** Optimal convergence of finite element approximation to an optimization problem with PDE constraint
15:00- 15:30	**Guanghui Hu:** Direct and inverse time-harmonic acoustic scattering from locally perturbed periodic curves	**De-Han Chen:** Variational source conditions for inverse problems in PDEs	**Hyea Hyun Kim:** Additive Schwarz algorithms for neural network approximations to partial differential equations	**Haijun Wu:** Finite element method for a nonlinear PML Helmholtz equation with high wave number	**Bui Trong Kien:** Regularity of solutions to a distributed and boundary optimal control problem governed by semilinear elliptic equations
15:30 - 16:00	**Nguyen Trung Thành:** Coefficient identification problems for advection-reaction equations with application in water quality modeling	**Rommel Real:** Hanke-Raus heuristic rule for Landweber iteration in Banach spaces	**Didit Adytia:** Combined numerical wave simulation with deep learning models for tsunami wave inversion and wave forecasting system	**Sudi Mungkasi:** Finite volume methods for solving the shallow water equations	**Kei Fong Lam:** Structural optimization with anisotropy: Application to 3D printing
16:00 - 16:30	Break	Break	Photo session and break	Break	Break
16:30 - 17:00	**Keji Liu:** Direct reconstruction methods in the stratified ocean waveguide	**Yi-Hsuan Lin:** The Calderón problem for nonlocal parabolic operators	**Rhudaina Mohammad:** Cellular rearrangement as L^2-gradient flow of weighted surface energy	**Ping Tong:** Elliptical anisotropic eikonal equation and its role in imaging the Earth's interior: A new modality of seismic imaging and some challenges	**Maurice Hensel:** Optimal control of quasilinear Maxwell variational inequalities
17:00 - 17:30	**Wenlong Zhang:** A new framework to quantify the uncertainty in general inverse problems	**Rolando Perez III:** Phase retrieval for wide band signals	**Yohanes Tjandrawidjaja:** The half-space matching method: The dissipative and non-dissipative cases	**Renier Mendoza:** Adjusting non-pharmaceutical interventions based on hospital bed capacity using a multi-operator differential evolution	**Luis Ammann:** Acoustic full-waveform inversion via optimal control
17:30 - 20:00					Closing and discussion
20:00 - 20:30		**Shuai Lu:** Increasing stability in the linearized inverse Schrödinger potential problems			
20:30 - 21:00		**Bowen Li:** Dielectric subwavelength resonances and their applications			
21:00 - 21:30		**Van Chien Le:** Existence of a weak solution to a nonlinear induction hardening problem for a steel workpiece			

Abstracts

Combined numerical wave simulation with deep learning models for tsunami wave inversion and wave forecasting system

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Abstract

Water wave modeling is a challenging problem yet, used in many applications in coastal engineering. The traditional way to model wave propagation is by simulating a wave model numerically. The wave model here is usually in the form of partial differential equations. Simulating the wave in a high-resolution grid or a long-term simulation requires high computation costs. This research combined numerical wave simulations with deep learning models to solve two wave-related problems. The first problem is to perform tsunami source inversion. In a landslide-generated tsunami, it is challenging to guest in the initial source of the tsunami, which is really needed to reconstruct a tsunami event. To solve this problem, we propose a deep learning supervised model to do the inversion of tsunami source form. To do so, we build training data by simulating numerically multiple tsunami generation scenarios by using a non-hydrostatic wave model. The deep learning-based tsunami inversion is performed by utilizing recorded buoy signals during the tsunami event as input to guess the initial waveform of the tsunami. We use the 2018 tsunami by Anak Krakatau in Indonesia as a study case. The second problem is to design a wave forecasting system based on numerical wave simulation and a deep learning model. In this case, we build a deep learning forecasting system based on training data obtained from numerical wave simulation. We use a phase-averaged model SWAN to perform a high resolution and long-term simulation to get 15 years of training data, which is then used for training of deep learning model: the Bidirectional Long-Term Memory (BiLSTM). The trained algorithm produces high accuracy prediction and is very efficient in computational time.

References

[1] D. Adytia, D. Saepudin, S. R. Pudjaprasetya, S. Husrin, and A. Sopaheluwakan. *A deep learning approach for wave forecasting based on a spatially correlated wind feature, with a case study in the Java Sea, Indonesia.*. Fluids 7, no. 1 (2022): 39.

[2] Adiwijaya, D. Adytia. *A Deep Learning Approach for Tsunami Source Inversion by using Tidal Gauge Data with Case Study in The 2018's Mount Anak Krakatau Tsunami.* In review process.

Acoustic Full-Waveform Inversion via Optimal Control

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Abstract

Full-waveform inversion (FWI) is a recent technique in seismic tomography to reconstruct physical parameters sampled by waves. Compared with other methods relying only on partial waveform information such as travel times or phase velocities, FWI exploits the entire waveform content. In this talk, we discuss an optimal control method for acoustic FWI. The aim is to reconstruct the speed wave parameter entering the hyperbolic PDE model in the coefficient of the second-order time derivative of the acoustic pressure. For the given optimization problem, we present necessary first-order optimality conditions based on adjoint techniques where the adjoint state has only low regularity properties. This is particularly favourable since then no Sobolev smoothing effect occurs in the optimal solution. Further, under specific regularity and compatibility assumptions, we present second-order sufficient optimality conditions. The talk will be concluded by numerical examples.

Variational source conditions for inverse problems in PDEs

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Abstract

The concept of variational source condition was introduced nearly 15 years ago, and has led to many important progress on the theory of regularization. This talk is devoted to some previous and recent developments of the theory of variational source conditions, with emphasis on convergence rate analysis for inverse problems in PDEs. We will briefly outline the connections of variational source conditions with convergence rates, optimality and reverse results of regularization theory. Then, applications to Tikhonov regularization of some concrete inverse source and coefficients problems in Hilbert settings are present. In the end, we will propose and analyze variational source conditions for the Tikhonov regularization methods with L^p-penalties applied to an ill-posed inverse elliptic problems.

Optimal convergence of finite element approximation to an optimization problem with PDE constraint

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Abstract

We present in this talk the optimal convergence of finite element approximation to an optimization problem with PDE constraint. Specifically, we consider an elliptic distributed optimal control problem without control constraints, which can also be viewed as a regularized inverse source problem. The main contributions are two-fold. First, we derive a priori and a posteriori error estimates for the optimization problems, under an appropriately chosen norm that allows us to establish an isomorphism between the solution space and its dual. These results yield error estimates with explicit dependence on the regularization parameter α so that the constants appeared in the derivation are independent of α. Second, we prove the contraction property and rate optimality for the adaptive algorithm with respect to the error estimator and solution errors between the adaptive finite element solutions and the continuous solutions. Extensive numerical experiments are presented that confirm our theoretical results.

References

[1] W. Gong, Z. Tan, Z. Zhou, *Optimal convergence of finite element approximation to an optimization problem with PDE constraint*, Inverse Problems, 38(2022), no. 4, Paper No. 045004, 45 pp.

Quasilinear Obstacle Problems in Ferromagnetic Shielding: Analysis and Optimal Control

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Abstract

In this talk, we aim to discuss the analysis and optimal control of a quasilinear first kind variational inequality (VI) in magnetostatics, in which first order differential constraints are imposed. Based on a Moreau-Yosida approximation for the indicator function of a specific underlying zeroth order obstacle set, we construct a sequence of approximating quasilinear variational problems where the occurring max-operation is smoothed. The corresponding limiting analysis leads to a well-posedness result and entails a dual formulation for VI.

More importantly, our construction comprises sufficient regularity, providing a suitable tool for studying optimality conditions corresponding to the optimal control of VI. Here, due to the character of the first order constraint, the main difficulty is that the sequence of Lagrangian multipliers appearing in the smoothed problems is suffering from poor stability properties. Thus, the characterization of the limiting (dual) multiplier needs a detailed investigation in which projection arguments play a crucial role.

Direct and inverse time-harmonic acoustic scattering from locally perturbed periodic curves

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Abstract

This talk is concerned with well-posedness of the forward scattering model and uniqueness of inverse scattering problems for recovering a local defect from far-field and near-field data. If the scattering interface is the graph of some function, we prove well-posedness for the time-harmonic acoustic scattering of plane waves from locally perturbed periodic surfaces. It will be shown that the scattered wave of an incoming plane wave is the sum of the scattered wave for the unperturbed periodic surface plus an additional scattered wave satisfying Sommerfeld's condition on the half-plane. Whereas the scattered wave for the unperturbed periodic surface has a far field consisting of a finite number of propagating plane waves, the additional field contributes to the far field by a far-field pattern defined in the half-plane directions similarly to the pattern known for bounded obstacles. We also discuss the well-posedness for non-self-intersecting scattering interfaces and the associated inverse scattering problems.

References

[1] G. Hu, W. Lu and A. Rathsfeld, *Time-harmonic acoustic scattering from locally perturbed periodic curves*, SIAM J. Appl. Math., 81 (2021): 2569-2595.

[2] G. Hu and A. Kirsch, *Time-harmonic scattering from locally perturbed periodic curves of Dirichlet and Neumann kind*, in preparation.

[3] G. Hu and A. Kirsch, *Direct and inverse time-harmonic scattering by Dirichlet periodic curves with local perturbations*, in preparation.

Regularity of solutions to a distributed and boundary optimal control problem governed by semilinear elliptic equations

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Abstract

In this talk, we present some recent results on the existence and regularity of solutions to an optimal control problem governed by semilinear elliptic equations with mixed pointwise constraints in which the controls act in the domain and on the boundary. We give some criteria under which the optimal solutions do exist and are Hölder continuous.

References

[1] H. Brezis, Functional Analysis, Sobolev Spaces and Partial Differential Equations, Springer, 2010.
[2] E. Casas, Boundary control of semilinear elliptic equations with pointwise state constraints, SIAM J. Control Optim. 4 (1993) 993–1006.
[3] E. Casas, M. Mateos, Second order optimality conditions for semilinear elliptic control problems with finitely many state constraints, SIAM J. Control Optim. 40 (2002) 1431–1454.
[4] N.B. Giang, N.Q. Tuan, N.H. Son, Regularity of Lagrange multipliers for mixed optimal control problem governed by semilinear elliptic equations, Positivity, accepted for publication.
[5] P. Grisvard, Elliptic Problems in Nonsmooth Domains, Pitman, Boston, 1985.
[6] B.T. Kien, V.H. Nhu, Second-order necessary optimality conditions for a class of semilinear elliptic optimal control problems with mixed pointwise constraints, SIAM J. Control Optim. 52 (2014) 1166–1202.
[7] B.T. Kien, V.H. Nhu, N.H. Son, Second-order optimality conditions for a semilinear elliptic optimal control problem with mixed pointwise constraints, Set-Valued Var. Anal. 25 (2016) 177–210.
[8] B.T. Kien, N.V. Tuyen, J-.C. Yao, Second-order KKT optimality conditions for multi-objective optimal control problems, SIAM J. Control Optim. 56 (2018) 4069–4097.
[9] B.T. Kien, N,T.T. Huong, X. Qinc, C.-F. Wen and J.-C. Yao, Regularity of solutions to a distributed and boundary optimal control problem governed by semilinear elliptic equations, J. Math. Anal. Appl., 495(2021)124694.
[10] A. Kufner, O. John, S. Fucik, Function Spaces, Noordhof International Publishing and Academi, Leyden and Prague, 1977.
[11] J.L. Lions, E. Magenes, Non-Homogeneous Boundary Value Problems and Applications I, Spinger-Verlag, Berlin, Heidel-berg, New York, 1972.
[12] A. Rösch, F. Tröltzsch, Existence of regular Lagrange multiplier for a nonlinear elliptic optimal control problem with pointwise control-state constraints, SIAM J. Control Optim. 45 (2006) 548–564.
[13] A. Rösch, F. Tröltzsch, On regularity of solutions and Lagrange multipliers of optimal control problems for semilinear equations with mixed pointwise control-state constraints, SIAM J. Control Optim. 46 (2007) 1098–1115.
[14] F. Tröltzsch, Optimal Control of Partial Differential Equations, Theory, Method and Applications, Americal Mathematical Society, Providence, Rhode Island, 2010.

Additive Schwarz algorithms for neural network approximations to partial differential equations

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Abstract

Neural network approximations to partial differential equations have been introduced and presented promising results in various application problems [1]-[3]. Recently, to address efficient and accurate solutions of the neural network approximations, partitioned neural networks and iterative schemes were studied in [4]-[7]. On the other hand, concrete convergence analysis on the iterative schemes, scalability by adopting a coarse component in the neural network solution, and parallel computing algorithms to alleviate the heavy communication cost were not fully answered in the previous studies. In the present work, to address these issues, additive Schwarz algorithms are revisited and reformulated to propose iterative solution procedures for neural network approximation and to provide concrete convergence analysis. Numerical results are presented to show performance of the proposed methods.

References

[1] M. Raissi, P. Perdikaris, G. E. Karniadakis. *Physics-informed neural networks: a deep learning framework for solving forward and inverse problems involving nonlinear partial differential equations*, Journal of Computational Physics Vol. 378 (2019), P. 686–707.

[2] J. Sirignano, K. Spiliopoulos. *DGM: a deep learning algorithm for solving partial differential equations*, Journal of Computational Physics Vol. 375 (2018), P. 1139–1364.

[3] E. Weinan, J. Han, A. Jentzen *Deep learning-based numerical methods for high-dimensional parabolic partial differential equations and backward stochastic differential equations*, Communications in Mathematics and Statistics Vol. 5, No. 4, (2017), P. 349–380.

[4] K. Li, K. Tang, T. Wu, Q. Liao *D3M: A deep domain decomposition method for partial differential equations*, IEEE Access Vol. 8, (2019), P. 5283–5294.

[5] W. Li, X. Xiang, Y. Xu *Deep domain decomposition method: Elliptic problems*, Mathematical and Scientific Machine Learning (2020), P. 269–286.

[6] A. D. Jagtap, E. Kharazmi, G. E. Karniadakis *Conservative physics-informed neural networks on discrete domains for conservation laws: Applications to forward and inverse problems*, Computer Methods in Applied Mechanics and Engineering Vol. 365, (2020), P. 113028.

[7] B. Moseley, A. Markham, T. Nissen-Meyer *Finite Basis Physics-Informed Neural Networks (FBPINNs): a scalable domain decomposition approach for solving differential equations*, arXiv preprint arXiv:2107.07871, (2021).

Structural optimization with anisotropy: Application to 3D printing

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Abstract

3D printing is an umbrella term for a set of technologies that manufacture highly intricate and complex designs not feasible with traditional die-casting or injection molding methods. But despite their popularization in recent years, several limitations prevent further integration of 3D printing into existing production lines. One recurring issue relates to overhangs, which are regions of the constructed object that when placed in a certain orientation extend outwards without any underlying support. Some of these overhangs can deform under their own weight and, if not supported from below, present a risk in damaging the printed object.

Conventional wisdom from practitioners says that overhangs whose outer normal makes an angle greater than 135 degrees with the upwards vertical direction should be supported from below with scaffolding. These are then removed after a successful print, but doing so will increase the material and processing costs. Another remedy is to modify the design to be self-supporting as much as possible without compromising its intended functionality. In this talk we consider the latter within a phase field structural topology optimization framework. Extending previous studies with a linearized elasticity model, we realize an overhang angle constraint with the help of anisotropic perimeter functionals, and study the corresponding optimal control problem. Numerical examples are provided to demonstrate how we discourage designs that develop overhangs not respecting the angle constraint. It turns out that for our approach we have to work with non-differentiable functionals, and thus we turn to subdifferential calculus to derive the first order optimality conditions.

References

[1] H. Garcke, K.F. Lam, R. Nürnberg and A. Signori. *Overhang penalization in additive manufacturing via phase field structural topology optimization with anisotropic energies*, Preprint arXiv:2111.14070 (2011)

Existence of a weak solution to a nonlinear induction hardening problem for a steel workpiece

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Abstract

We discuss a mathematical model for an induction hardening process of a steel workpiece. The electromagnetic process is described by the eddy current equations, which are coupled with the energy balance in the workpiece via the heat equation and the kinetic phase transition. The nonlinearity of the system are caused by a nonlinear relation between the magnetic induction and the magnetic field, together with a nonlinear heat conduction and the Joule heating effect. We propose a time discretization for the variational system, and perform some a priori estimates for discrete solutions. By aid of Rothe's method and the theory of monotone operators, we show the existence of a weak solution to the variational problems. The uniqueness of a solution is still a challenge for future work.

References

[1] V. C. Le, M. Slodička, K. Van Bockstal. *Existence of a weak solution to a nonlinear induction hardening problem with Leblond–Devaux model for a steel workpiece*, Communications in Nonlinear Science and Numerical Simulation 107 (2022), 106156.

Dielectric subwavelength resonances and their applications

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Abstract

In this talk, we discuss the resonant behaviors of EM waves in high contrast media and their applications. We first define the EM scattering resolvent and introduce the dielectric subwavelength resonances. The a priori estimates for dielectric resonances and the associated resonant modes are derived. Then we address the existence of the scattering resonances in the high contrast regime and analyse their limiting behaviors when the contrast parameter tends to infinity. We also analyze the enhancements of the scattered fields and the cross-sections when the dielectric resonances happen. We develop a novel multipole radiation framework and show that at the resonant frequencies, the nanoparticles with high refractive indices behave like the coupling of an electric dipole with a resonant magnetic dipole. We then turn to the analysis of the super-resolution phenomenon in the time-reversal imaging of the EM radiating sources embedded in high contrast media. We establish the connection between the resolution and the outgoing resolvent of the Maxwell operator. A linear approximation of the resolution is obtained in terms of eigenvalues and eigenfunctions. If time permits, we will talk about the high contrast EM metasurface and characterize the conditions under which the Fano resonances can happen.

References

[1] H. Ammari, B. Li, J. Zou. *Superresolution in recovering embedded electromagnetic sources in high contrast media*, SIAM J. Imaging Sci., 13 (2020), 1467-1510.

[2] H. Ammari, B. Li, J. Zou. *Mathematical analysis of electromagnetic scattering by dielectric nanoparticles with high refractive indices*, Accepted by Trans. Amer. Math. Soc.

[3] H. Ammari, B. Li, H. Li, J. Zou. *Bound states in the continuum for electromagnetic high contrast metasurfaces*

Convergent finite element methods for the perfect conductivity problem with close-to-touching inclusions

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Abstract

In the perfect conductivity problem of high-contrast composite materials, the gradient of the electric field is often very large in a narrow region between two inclusions and blows up as the distance between the inclusions tends to zero. The rigorous error analysis for the computation of such perfect conductivity problems with close-to-touching inclusions of general geometry still remains open in three dimensions. We address this problem by establishing new asymptotic estimates for the second-order partial derivatives of the solution with explicit dependence on the distance ε between the inclusions, and use the asymptotic estimates to design a class of graded meshes and finite element spaces to solve the perfect conductivity problem with possibly close-to-touching inclusions. In particular, we propose a special finite element basis function which resolves the asymptotic singularity of the solution by making the interpolation error bounded in $W^{1,\infty}$ in a neighborhood of the close-to-touching point, even though the solution itself is blowing up in $W^{1,\infty}$. This is crucial in the error analysis for the numerical approximations. We prove that the proposed method yields optimal-order convergence in the H^1 norm, uniformly with respect to the distance ε between the inclusions, in both two and three dimensions for general convex smooth inclusions which are possibly close-to-touching. Numerical experiments are presented to support the theoretical analysis and to illustrate the convergence of the proposed method for different shapes of inclusions in both two- and three-dimensional domains.

References

[1] B. Li, H. Li, and Z. Yang: *Convergent finite element methods for the perfect conductivity problem with close-to-touching inclusions*, submitted.

Analytic recovery of a planar conductivity inclusion with a Lipschitz boundary

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Abstract

In this talk, I present an analytic method for the inverse problem of determining a planar conductivity inclusion, which is assumed to be isotropic and homogeneous with arbitrary constant conductivity. A conductivity inclusion inserted in a homogeneous background induces a perturbation in the background potential. The perturbation admits a multipole expansion, whose coefficients are the so-called generalized polarization tensors (GPTs) and can be obtained from exterior measurements. For a simply connected planar domain, there exists uniquely an exterior Riemann mapping that maps the exterior of a disk to the exterior of the domain. By knowing the coefficients of the Riemann mapping, one can determine the location and shape of the inclusion. I will provide explicit expressions in terms of the GPTs for the Riemann mapping coefficients of an inclusion that has either a smooth boundary or a Lipschitz boundary with a star-shaped condition. The expression formulas are derived from matrix factorizations of the GPTs by using the concept of the Faber polynomial polarization tensors. This work is a joint work with Doosung Choi, Johan Helsing and Sangwoo Kang.

References

[1] D. Choi, J. Kim, and M. Lim. *Analytical shape recovery of a conductivity inclusion based on Faber polynomials*, Math. Ann. 381 (2021), P. 1837–1867.
[2] D. Choi, J. Helsing, S. Kang, M. Lim. *Inverse problem for a planar conductivity inclusion*, arXiv:2206.05593.

The Calderón problem for nonlocal parabolic operators

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Abstract

In this talk, we demonstrate that nonlocal parabolic inverse problems can be reduced to their local counterparts. We build several connections between the nonlocal and local inverse problems for parabolic equations, by using their corresponding measurements. This is a joint work with Prof. Gunther Uhlmann.

Wave patterns inside transparent scatterers and applications

Hongyu Liu*

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Abstract

I shall discuss our recent discoveries on the global and local patterns of wave propagation inside transparent scatterers. Those discoveries produce interesting applications in super-resolution wave imaging, surface plasmon polariton resonances and artificial mirage.

References

[1] H. Liu, *On local and global structures of transmission eigenfunctions and beyond*, J. Inverse Ill-Posed Probl. 30 (2022), no. 2, 287-305.

Direct Reconstruction Methods in the Stratified Ocean Waveguide

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Abstract

The scattering problems of marine acoustics have attracted great attention in recent years since they have wide applications in identifications of submarines, mineral deposits, wreckages, reef, submerged scatterers, etc. In this talk, we shall present the inverse problems and the corresponding direct reconstruction methods in the stratified ocean waveguide. The direct reconstruction methods can be viewed as simple and efficient numerical techniques for providing reliable initial approximate locations of the marine sources and scatterers for any existing more refined and advanced but computationally more demanding algorithms to recover the accurate physical profiles. The detailed information of direct reconstruction methods are stated in [3, 4, 5, 6, 7], and [3, 4] are joint works with Prof. Xu and Prof. Zou.

References

[1] D. Ahluwalia and J. Keller, *Exact and asymptotic representations of the sound field in a stratified ocean*, in Wave Propagation and Underwater Acoustics, Lecture Notes in Phys. **70** (1977), Springer, Berlin, 14-85.

[2] J. Buchanan, R. Gilbert, A. Wirgin and Y. Xu, *Marine acoustics: Direct and inverse problems*, SIAM, Philadelphia, 2004.

[3] K. Liu, Y. Xu and J. Zou, *A multilevel sampling method for detecting sources in a stratified ocean waveguide*, J. Comput. Appl. Math. **309** (2017), 95-110.

[4] K. Liu, Y. Xu and J. Zou, *Direct recovery of wave-penetrable scatterers in a stratified ocean waveguide*, J. Comput. Appl. Math. **338** (2018), 239-257.

[5] K. Liu, *Direct imaging of inhomogeneous obstacles in a three-layered ocean waveguide*, Commun. Comput. Phys., **26** (2018), 700-718.

[6] K. Liu, *Near-field imaging of inhomogeneities in a stratified ocean waveguide*, J. Comput. Phys. **398** (2019), 108901.

[7] K. Liu, *Fast imaging of sources and scatterers in a stratified ocean waveguide*, SIAM J. Imag. Scien. **14** (2021), 224-245.

Increasing stability in the linearized inverse Schrödinger potential problems

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Abstract

Inverse Schrödinger potential problem concerns about the recovery of a potential function in the Schrödinger equation in a bounded domain throught the DtN map. In this talk, we introduce the linearized DtN map, and prove a stability estimate with explicit dependence on wavenumbers. This is an increasing stability result, in the sense that the logarithmic stable term decays when wavenumber increases. The talk is based on joint works with Victor Isakov (Wichita), Mikko Salo (Jyväskylä), Boxi Xu (SUFE) and Sen Zou (Fudan).

References

[1] Isakov, Victor; Lu, Shuai; Xu, Boxi *Linearized inverse Schrödinger potential problem at a large wavenumber.* SIAM J. Appl. Math. 80 (2020), no. 1, 338–358.

[2] Isakov, Victor; Lu, Shuai; Xu, Boxi *A linearised inverse conductivity problem for the Maxwell system at a high frequency.* J. Comput. Phys. 455 (2022), Paper No. 111003, 18 pp.

[3] Lu, Shuai; Salo, Mikko; Xu, Boxi *Increasing stability in the linearized inverse Schrödinger potential problem with power type nonlinearities.* Inverse Problems 38 (2022), no. 6, Paper No. 065009, 25 pp.

[4] Sen Zou; Lu, Shuai; Xu, Boxi *Linearized inverse schrödinger potential problem with partial data and its Deep Neural Network inversion.* Submitted.

A learning framework for mapping problems based on Quasiconformal Geometry

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Abstract

Many imaging problems can be formulated as a mapping problem. A general mapping problem aims to obtain an optimal mapping that minimizes an energy functional subject to the given constraints. Existing methods to solve the mapping problems are often inefficient and can sometimes get trapped in local minima. An extra challenge arises when the optimal mapping is required to be diffeomorphic. In this talk, we address the problem by proposing a deep-learning based framework based on the Quasiconformal (QC) Teichmüller theories. The main strategy is to learn the Beltrami coefficient (BC) that represents a mapping as the latent feature vector in the deep neural network. The BC measures the geometric distortions under the mapping. As such, the proposed network based on QC theories is explainable. Another crucial advantage of the proposed framework is that once the network is successfully trained, the optimized mapping corresponding to each input data information can be obtained in real time. In this talk, we will illustrate our framework by applying it to solve the diffeomorphic image registration problem. The developed network, called the quasiconformal registration network (QCRegNet), outperforms other state-of-the-art image registration models. This work is supported by HKRGC GRF (Project ID: 14305919).

Adjusting non-pharmaceutical interventions based on hospital bed capacity using a multi-operator differential evolution

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Abstract

Without vaccines and medicine, non-pharmaceutical interventions (NPIs) such as social distancing, have been the main strategy in controlling the spread of COVID-19. Strict social distancing policies may lead to heavy economic losses, while relaxed social distancing policies can threaten public health systems. We formulate an optimization problem that minimizes the stringency of NPIs during the prevaccination and vaccination phases and guarantees that cases requiring hospitalization will not exceed the number of available hospital beds. The approach utilizes an SEIQR model that includes a parameter that quantifies NPIs (μ) and separates mild from severe cases. Payoff constraints ensure that daily cases are decreasing at the end of the prevaccination phase and that there are minimal cases at the end of the vaccination phase. Using the penalty method, the constrained minimization is transformed to a non-convex, multi-modal unconstrained optimization problem, which is solved using a metaheuristic algorithm called the improved multi-operator differential evolution. Moreover, we apply the framework to determine optimal social distancing policy strategies in the Republic of Korea considering different amounts and types of antiviral drugs. The model for Korea also takes into account the delta and omicron variants, booster shots, and waning of immunity. The resulting optimal μ values show that fast administration of vaccines is as important as using highly effective vaccines. The initial number of infected individuals and daily imported cases should be kept minimum especially when the severe bed capacity is low. In Korea, a gradual easing of NPIs without exceeding the severe bed capacity is possible if there are at least seven million antiviral drugs and the effectiveness of the drug in reducing the severity of the disease is at least 86%. The optimization approach uses a mathematical model to propose strategies for the gradual easing of NPIs without exceeding the hospital bed capacity. Model parameters can be adapted to fit a specific country or region and can also be used for other infectious diseases. The framework can be used as a decision support tool in planning practical and economic policies, especially in countries with limited healthcare resources.

References

[1] K. M. Sallam, S. M. Elsayed, R. K. Chakrabortty, M. J. Ryan, *Improved multi-operator differential evolution algorithm for solving unconstrained problems*, in: 2020 IEEE Congress on Evolutionary Computation (CEC), (2020), pp. 1–8.

[2] J. Lee, R. Mendoza, V. M. P. Mendoza, Y. Ko, J. Lee, Y. Seo, E. Jung, *Modelling the effects of social distancing, antiviral therapy, and booster shots on mitigating omicron spread*, Research Square, https://doi.org/10.21203/rs.3.rs-1322738/v1, (2022), preprint

Cellular rearrangement as L^2-gradient flow of weighted surface energy

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Abstract

In this paper, we proposed a level set-based computational framework to model observed cellular patterns in developing sensory systems, in particular, olfactory and auditory epithelia. To analyze this, we assume, as in the vertex dynamics model, that tissue evolves via a succession of quasi-equilibrium states, that is, cell shapes are described by their instantaneous state of lowest energy. To be precise, we treat cellular rearrangements as the L^2-gradient flow of the weighted cell surface energy constrained by each cell's prescribed volume. Here the weights are derived from measured values such as cell-cell adhesion or interfacial tension. In addition, we assume that no apoptosis occurs during the evolution, as observed in embryonic stages E14 to E18 and postnatal stage P1. Due to the implicit nature of the proposed numerical method, complex topology changes including frequent cell intercalations, are easily handled without the need for ad hoc algorithms.

References

[1] R. Mohammad, H. Murakawa, K. Svadlenka, H. Togashi. A numerical algorithm for modeling cellular rearrangements in tissue morphogenesis, Communications Biology 5:239 (2022), https://doi.org/10.1038/s42003-022-03174-6.

Finite Volume Methods for Solving the Shallow Water Equations

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Abstract

Shallow water equations have been used widely to model water flows, such as floods and tsunamis, on open channels. Solving these equations fast and accurately is desired. This system of equations is in the form of partial differential equations of the hyperbolic type, so it admits discontinuous solutions. Therefore, finite volume methods are suitable for solving these equations. This is because finite volume methods are developed based on integral forms of conservation laws. Note that integral is defined for both continuous and discontinuous functions. In this talk, I will present finite volume methods for solving the shallow water equations in one and two dimensions. I will cover three kinds of finite volume methods, namely, standard, staggered, and adaptive finite volume methods. In the final part of the talk, I will note some open problems in this area of research.

Coefficient identification problems for advection-reaction equations with application in water quality modeling

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Abstract

We discuss coefficient identification problems for a system of one-dimensional advection-reaction equations. The considered equations describe the transportation of pollutants in rivers or streams. We will discuss the stability using Carleman estimates and numerical methods for solving these inverse problems. We will demonstrate the performance of the proposed algorithms using simulated data generated using a realistic scenario. The research of this talk is supported by Vingroup Innovative Foundation under grant number VINIF.2020.DA16.

Phase Retrieval for Wide Band Signals

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Abstract

The study of phase retrieval involves the recovery of a function f in some function space from given data about the magnitude $|f|$ and other assumptions on f, where these other assumptions can be in terms of some transform of f. In this talk, we solve the phase retrieval problem for wide-band signals. We solve the following problem: given $f \in L^2(\mathbb{R})$ with Fourier transform in $L^2(\mathbb{R}, e^{2c|x|}dx)$, we find all functions $g \in L^2(\mathbb{R})$ with Fourier transform in $L^2(\mathbb{R}, e^{2c|x|}dx)$, such that $|f(x)| = |g(x)|$ for all $x \in \mathbb{R}$. To do so, we first translate the problem to functions in the Hardy spaces on the disc via a conformal bijection, and take advantage of the inner-outer factorization. We also consider the same problem with additional constraints involving some transforms of f and g, and determine if these constraints force uniqueness of the solution. This was a joint work with Philippe Jaming and Karim Kellay.

References

[1] P. Jaming, K. Kellay, and R. Perez III. *Phase retrieval for wide band signals*, J. Fourier Anal. Appl., 26 (2020), Article No. 54, 21 pp.

Hanke-Raus heuristic rule for Landweber iteration in Banach spaces

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Abstract

We consider the Landweber iteration for solving linear as well as nonlinear inverse problems in Banach spaces. Based on the discrepancy principle, we propose a heuristic parameter choice rule for choosing the regularization parameter which does not require the information on the noise level, so it is purely data-driven. According to a famous veto, convergence in the worst-case scenario cannot be expected in general. However, by imposing certain conditions on the noisy data, we establish a new convergence result which, in addition, requires neither the Gâteaux differentiability of the forward operator nor the reflexivity of the image space. Therefore, we also expand the applied range of the Landweber iteration to cover non-smooth ill-posed inverse problems and to handle the situation that the data is contaminated by various types of noise. Numerical simulations are also reported.

References

[1] M. Hanke, T. Raus,. *A general heuristic for choosing the regularization parameter in ill-posed problems*, SIAM Journal on Scientific Computing. 17.4 (1996), P. 956–972.

[2] Q. Jin, W. Wang. *Landweber iteration of Kaczmarz type with general non-smooth convex penalty functionals*, Inverse Problems. 29.8 (2013), P. 1–22.

[3] R. Real, Q. Jin. *A revisit on Landweber iteration*, Inverse Problems. 36 (2020), P. 22–42.

The half-space matching method: The Dissipative and non-dissipative cases

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Abstract

We have developed a new method for scattering problems in anisotropic media, where usual numerical methods are either too expensive or even not applicable. This so-called Half-Space Matching method has been first developed and validated in 2D. It consists in coupling several plane-wave representations of the solution in half-spaces surrounding the scatterer with a Finite Element computation of the solution around the scatterer. To ensure that all these representations match in the infinite intersections of the half-spaces, the traces of the solution on the edges of the half-planes are linked by Fourier-integral equations. In the case of a dissipative medium, the continuous problem is proved to be coercive plus compact, and the convergence of the discretization is ensured.

In the case of a non-dissipative medium, the traces of the solutions decay at infinity as $\frac{1}{\sqrt{r}}$ which is not in L^2. Therefore, we develop a slightly different HSM formulation, where we use, instead of the traces, their analytic extensions (for complex spatial variable) as unknowns. Since these analytic extensions decay exponentially, the analysis of this new complex-scaled HSM formulation can be done in the L^2 framework in a similar manner to what has been done in the dissipative case.

References

[1] A.-S. Bonnet-BenDhia, S. Chandler-Wilde, S. Fliss, C. Hazard, K.-M. Perfekt, Y. Tjandrawidjaja. *The complex scaled Half-Space Matching method*, SIAM Mathematical Analysis (2022).

[2] Y. Tjandrawidjaja. *Some contributions to the analysis of the Half-Space Matching Method for scattering problems and extension to 3D elastic plates*, PhD thesis, Université Paris-Saclay (2019).

Elliptical Anisotropic Eikonal Equation and Its Role in Imaging the Earth's Interior: A New Modality of Seismic Imaging and Some Challenges

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Abstract

Many fundamental problems in Earth sciences, including the determination of earthquake locations, the delineation of the 3D volumetric structure, and the detection of the boundary between soft soil and hard rocks, are formulated as PDE-constrained optimization problems. Wave equation-constrained inverse problems have gained their popularity during the past two decades, because of their theoretical advantages over conventional ray-theory based techniques in resolving structural variations with dimensions smaller than the dominant wavelength. In reality, however, this may not be (always) true, mainly due to the lack of an accurate initial model and the high demand for computational resources. As one of the first few attempts in Earth sciences, we turn to the one-dimension-less elliptical anisotropic eikonal equation and use it to model seismic wave propagation in anisotropic media. Solving the related inverse problem can not only determine subsurface velocity heterogeneity but also seismic anisotropy, with reliability and computational efficiency. Note that seismic anisotropy is a key parameter reflecting the past and ongoing deformation history of the Earth planet on various scales. In this talk, I will show how the inverse problem is formulated and solved. I will also address the challenges we are currently facing.

Finite Element Method for a Nonlinear PML Helmholtz Equation with High Wave Number

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Abstract

A nonlinear Helmholtz equation (NLH) with high wave number and Sommerfeld radiation condition is approximated by the perfectly matched layer (PML) technique and then discretized by the linear finite element method (FEM). Wave-number-explicit stability and regularity estimates and the exponential convergence are proved for the nonlinear truncated PML problem. Preasymptotic error estimates are obtained for the FEM, where the logarithmic factors in h required by the previous results for the NLH with impedance boundary condition are removed in the case of two dimensions. Moreover, local quadratic convergences of the Newton's methods are derived for both the NLH with PML and its FEM. Numerical examples are presented to verify the accuracy of the FEM, which demonstrate that the pollution errors may be greatly reduced by applying the interior penalty technique with proper penalty parameters to the FEM. The nonlinear phenomenon of optical bistability can be successfully simulated.

A new framework to quantify the uncertainty in general inverse problems

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Abstract

In this work, we investigate the regularized solutions and their finite element solutions to the inverse source problems governed by partial differential equations, and establish the stochastic convergence and optimal finite element convergence rates of these solutions, under point wise measurement data with random noise. The regularization error estimates and the finite element error estimates are derived with explicit dependence on the noise level, regularization parameter, mesh size, and time step size, which can guide practical choices among these key parameters in real applications. The error estimates also suggest an iterative algorithm for determining an optimal regularization parameter. Numerical experiments are presented to demonstrate the effectiveness of the analytical results.

References

[1] Z. Chen, R. Tuo and W. Zhang, Stochastic Convergence of A Nonconforming Finite Element Method for the Thin Plate Spline Smoother for Observational Data, SIAM Journal on Numerical Analysis, 2018, 56: 635-659.

[2] Z. Chen, R. Tuo and W. Zhang, A Balanced Oversampling Finite Element Method for Elliptic Problems with Observational Boundary Data, Journal of Computational Mathematics, 2020, 38, 355-374.

[3] Zhiming Chen, Wenlong Zhang, Jun Zou, Stochastic convergence of regularized solutions and their finite element approximations to inverse source problems, SIAM Journal on Numerical Analysis, 2022, 60(2), 751-780.